Engineering Structures 85 (2015) 219–233

Contents lists available at ScienceDirect

Engineering Structures

journal homepage: www.elsevier.com/locate/engstruct

Free from damage beam-to-column joints: Testing and design of DST connections with friction pads

Massimo Latour *, Vincenzo Piluso, Gianvittorio Rizzano

University of Salerno, Civil Engineering Department, Salerno, Italy

ARTICLE INFO

Article history:
Received 16 May 2014
Revised 14 October 2014
Accepted 9 December 2014
Available online 2 January 2015

Keywords:
Friction
Experimental
Design
Joints
Cyclic
Dissipative
Damper
No damage

ABSTRACT

Dealing with the seismic behavior of steel MRFs, in last decade, the adoption of dissipative partial-strength beam-to-column joints has started to be considered an effective alternative to the traditional design approach which, aiming to dissipate the seismic input energy at beam ends, suggests the use of full-strength joints. On the base of past experimental results, the use of dissipative Double Split Tee (DST) connections can be considered a promising solution from the technological standpoint, because they can be easily replaced after the occurrence of a seismic event. Nevertheless, their dissipation supply under cyclic loads has been demonstrated to be characterized by significant pinching and strength degradation which undermine the energy dissipation capacity. The need to overcome these drawbacks to gain competitive technological solutions has suggested an innovative approach based on the integration of beam-to-column joints by means of friction dampers located at the beam flange level. Therefore, the use of partial strength DST joints equipped with friction pads is proposed. Aiming to the assessment of the cyclic rotational response of such innovative connections, two experimental programs have been undertaken. The first one has been aimed at characterizing the dissipative performances of five frictional interfaces to be employed as dampers. The second one is aimed at the application of the same materials to DST joints specifically designed for dissipating the seismic input energy in a couple of friction dampers located at the beam flanges level. The results of the experimental analysis carried out at the Materials and Structures Laboratory of Salerno University are herein presented, showing the potential of the proposed damage-free beam-to-column joints.

1. Introduction

According to performance based design, structures in seismic zones have to be designed in order to withstand frequent earthquakes without significant damages and to remain safe, even though a certain amount of structural damage is accepted, in case of seismic events with high return period. In particular, dealing with Moment Resisting steel Frames, according to the most recent seismic codes they can be designed in order to concentrate the energy dissipation capacity at the beam ends [8] or in the connections [36,3,2], even if such second possibility is sometime limited only to the case of ordinary moment frames [1]. In the former case, the characteristics of the frame at the Ultimate Limit State (ULS) depend on the plastic rotation capacity and energy dissipation supply of steel members that have to develop wide and stable hysteresis loops [27,17,6,15]. In the latter case, the energy dissipation supply of the frame depends on the ability of connections to withstand excursions in plastic range without losing their capacity to withstand vertical loads [4,22]. In such a case, as far as the dissipative capacity of the frame depends on the connections, it is necessary to properly characterize and predict their response under monotonic and cyclic loading conditions [26,5,18,19,20,28,7,40,37,32].

To this aim, in the last two decades, a number of experimental programs dealing with the characterization of the cyclic behavior of beam-to-column connections have been carried out [11,47,48,50,12,13,44,39,16,42,43]. In a work by the same authors, the behavior of four bolted joints, designed to possess the same strength, but detailed to involve in the plastic range different components, has been assessed pointing out the main features of the hysteretic behavior of classical connections [24]. Within this activity, Double Split Tee connections have been recognized as an interesting solution to be applied in dissipative semi-continuous MRFs. In fact, DST connections can be easily repaired after destructive seismic events and allow to govern the design process by simply calibrating three geometrical parameters: the width and the

* Corresponding author.
E-mail addresses: mlatour@unisa.it (M. Latour), v.piluso@unisa.it (V. Piluso), g.rizzano@unisa.it (G. Rizzano).

http://dx.doi.org/10.1016/j.engstruct.2014.12.019

thickness of the T-stub flange plate and the distance between the bolts and the plastic hinge arising at the stem-to-flange connection. On the other hand, beam-to-column joints engaging in plastic range bolted components suffer from several disadvantages. In fact, even though experimental studies demonstrate that bolted components are able to dissipate significant amounts of energy, they have an hysteretic behavior affected by pinching phenomena due to contact phenomena and plastic deformation of the bolts, which usually lead to the deterioration of strength and stiffness of the tee elements.

A possible strategy to overcome the above drawbacks of DST joints has recently been suggested by [33–35]. In particular, in order to improve the hysteretic behavior of DST joints, the authors have proposed to include within the traditional structural detail of DST connections an hysteretic damper realized by cutting the flange plates of the T-stub elements, in the region between the stem and the bolts, according to an hourglass shape similar to the classical ADAS device (Added Stiffness and Damping). In this way, a significant improvement of the performances of DST joints under cyclic loads can be obtained by enhancing the low cycle fatigue resistance of the dissipative joint components. A similar approach, based on the use of hysteretic dampers, has been suggested by [29] with reference to joints realized with top and seat angles. In particular, the authors propose to substitute the classical rectangular angle with an hysteretic damper constituted by an angle and a vertical rib in which slits and holes are made in order to concentrate the dissipation in zones specifically designed for absorbing energy.

The use of beam-to-column connections equipped with passive energy dissipation devices has been suggested also by other researchers. In particular, Suita et al. [46] and Inoue et al. [25] have proposed the use of Buckling Restrained Braces (BRB) to be connected between the beam flange and the column flange close to the member ends. The top beam flange is pin connected to the column flange, so that the bending moment is transmitted by means of the BRBs axial force acting with a given lever arm. Both double-side bracing configuration and single-side bracing configuration have been proposed for such weld-free beam-to-column connections.

Similarly, Kishiki et al. [30] have proposed a beam-to-column connection where the top beam flange is connected to the column flange by means of a bolted T-stub, with stiffened stem, fixing the point of rotation while the bottom beam flange is connected to the column flange with a bolted T-stub whose stem has a dog-bone shape and is restrained by an additional plate to prevent its buckling in compression. Therefore, the bottom T-stub is conceived to work as a BRB.

Oh et al. [41] have proposed the use of a beam-to-column connection typology where the top beam flange is connected to the column flange by means of a fixed bolted T-stub, namely split T, while the bottom beam flange is connected to the column flange by means of a slit damper. The connection is design to behave as a partial strength connection where the energy dissipation capacity is provided by the slit damper.

The use of hysteretic dampers has been also suggested to improve the cyclic response of beam-to-column moment connections for column weak axis. In particular, the connection typology conceived by Koetaka et al. [31] is characterized by the use of splice plates to connect the top beam flange to a continuity plate welded to the column web and flanges while the bottom beam flange is connected to the continuity plate by means of two omega shaped hysteretic dampers.

More recently, Yeung et al. [49] have proposed beam-to-column connections with asymmetric friction dampers as connecting elements between the beam bottom flange and the column flange while the center of rotation is fixed by means of a flange plate bolted to the beam top flange and welded to the column flange.

Within the above framework, in this paper a new approach for increasing the energy dissipation capacity of beam-to-column joints of Moment Resisting steel Frames (MRFs) is presented. In particular, it is proposed to modify the classical DST joint detail by adding a friction pad between the T-stub stem and the beam flange which has to be designed in order to prevent its slippage under serviceability limit states and to be activated under severe seismic loading conditions. With the proposed approach the friction mechanism is used to dissipate the seismic input energy and the component method is applied in order to prevent the plastic engagement of other joint components. In addition, because of energy dissipation by friction, the primary connection components practically result free from damage. Therefore, when connections are practically not affected by any damage, non-yielding structures can be designed provided that design criteria rigorously assuring that columns remain in elastic range are applied. Even though the goal of non-yielding structures can be considered a significant advance with respect to traditional moment-resisting frames, it is important to underline that it does not mean that the building is free from damage. In fact, on one hand, it has to be considered that the connections proposed will not snap back to the original configuration, resulting in a permanent drift requiring a recentering in the aftermath of earthquake. On the other hand, large damage could potentially result to non-structural components due to transient and permanent drift. Therefore the connection details between the structural and non-structural components need to be conceived to accommodate such displacements.

The paper is organized in two parts providing the main results of two experimental activities dealing with the friction components and with the whole beam-to-column joints, respectively. In the first part, with the aim of understanding the potentialities of a number of interfaces to be applied as energy dampers, an experimental study on friction materials is carried out. In particular, three different interfaces are considered: two adopting friction rubber-based materials and one using brass plates, all sliding on steel. All the specimens are clamped by means of high strength bolts and are tested under cyclic loading conditions in order to obtain slippage loads compatible with applications to partial strength joints. In the second part of the work, the same friction materials are applied to an innovative partial strength beam-to-column joint where friction pads are located at the beam flange level. The cyclic behavior of the proposed joints is investigated by means of experimental tests under displacement control on real scale external beam-to-column joints. In particular, as shown in the following, four innovative Double Split Tee (DST) joints are designed aiming to dissipate the seismic input energy by means of the slippage of the stems of the tees on a layer of friction material [38], which is interposed between the tee stems and the beam flanges. In this way, under cyclic loading conditions, structural elements do not undergo any damage and the energy dissipation is provided by the alternate movement of the tee stems on the friction pads, which are preloaded by means of high strength bolts.

2. Experimental tests on friction materials

Preliminarily, in order to investigate the possibility of applying a friction damper within the components of a beam-to-column joint, the frictional properties of different interfaces have been analyzed by designing a sub-assemblage to be tested under uniaxial loading conditions. In particular, the tested device is constituted by a layer of friction material that has been placed between plates made of S275 steel (Fig. 1). In order to allow the relative movement of the steel on the interposed friction material, one of the inner plates has been realized with slotted holes.